JC02 Rec'd PCT/PTO 15 DEC 2000

Form PTO-1390 (REV 10-95) U.S DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371		ATTORNEY'S DOCKET NUMBER **702-002116** U.S. APPLICATION NO (If known, see 37 CFR 1.5) 09/719757
INTERNATIONAL APPLICATION NO. **PCT/BE99/00076**	INTERNATIONAL FILING DATE **14.06.99 (June 14, 1999)**	PRIORITY DATES CLAIMED **16.06.98 (June 16, 1998)** **13.10.98 (October 13, 1998)**

TITLE OF INVENTION **METHOD AND DEVICE FOR CORRECTING PROXIMITY EFFECTS**

APPLICANT(S) FOR DO/EO/US **Dirk E. M. VAN DYCK and Piotr Tomasz JEDRASIK**

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C 371
3. ☒ This express request to begin national examination procedures (35 U.S.C 371(f)) at any time rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(1)
4. ☒ A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.
5. ☒ A copy of the International Application as filed (35 U.S.C 371(c)(2))
   a. ☐ is transmitted herewith (required only if not transmitted by the International Bureau).
   b. ☒ has been transmitted by the International Bureau.
   c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).
6. ☐ A translation of the International Application into English (35 U.S.C. 371(c)(2)).
7. ☒ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C 371(c)(3))
   a. ☐ are transmitted herewith (required only if not transmitted by the International Bureau).
   b. ☐ have been transmitted by the International Bureau.
   c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
   d. ☒ have not been made and will not be made.
8. ☐ A translation of the amendments to the claims under PCT Article 19 (35 U.S.C 371(c)(3)).
9. ☐ An oath or declaration of the inventor(s) (35 U.S.C 371(c)(4)).
10. ☐ A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

Items 11. to 16. below concern document(s) or information included:

11. ☐ An Information Disclosure Statement under 37 CFR 1.97 and 1.98
12. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included
13. ☒ A FIRST preliminary amendment.
    ☐ A SECOND or SUBSEQUENT preliminary amendment.
14. ☐ A substitute specification.
15. ☐ A change of power of attorney and/or address letter.
16. ☒ Other items or information
    a. WO 99/66530-Front Page with Abstract, specification claims and drawings (21 pp.)
    b. Search Report (3 pp.)
    c. International Preliminary Examination Report and Annexes (9 pp.)

(January 1996)

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U.S. APPLICATION NO (If known, see 37 CFR 1.5) 09/719757	INTERNATIONAL APPLICATION NO. **PCT/BE99/00076**	ATTORNEY'S DOCKET NUMBER **702-002116**

17. ☒ The following fees are submitted: **BASIC NATIONAL FEE (37 CFR 1.492(a)(1)-(5)):** Search Report has been prepared by the EPO or JPO .... **$860.00** International preliminary examination fee paid to USPTO (37 CFR 1.482) .... **$690.00** No international preliminary examination fee paid to USPTO (37 CFR 1.482) but international search fee paid to USPTO (37 CFR 1.445(a)(2))........ **$710.00** Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO................. **$1000.00** International preliminary examination fee paid to USPTO (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33(2)-(4).................... **$100.00**	CALCULATIONS	PTO USE ONLY
ENTER APPROPRIATE BASIC FEE AMOUNT =	$ 860.00	
Surcharge of **$130.00** for furnishing the oath or declaration later than ☐ 20 ☒ 30 months from the earliest claimed priority date (37 CFR 1.492(e))	$ 130.00	

CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE		
Total claims	17 - 20	0	X $18.00	$ 0.00	
Independent claims	2 - 3 =	0	X $80.00	$ 0.00	
MULTIPLE DEPENDENT CLAIM(S) (if applicable)			+ $270.00	$ 0.00	
TOTAL OF ABOVE CALCULATIONS =				$ 990.00	
Reduction of 1/2 for filing by small entity, if applicable Verified Small Entity Statement must also be filed (Note 37 CFR 1.9, 1.27, 1.28).				$ 0.00	
SUBTOTAL =				$ 990.00	
Processing fee of **$130.00** for furnishing the English translation later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492(f)). +				$ 0.00	
TOTAL NATIONAL FEE =				$ 990.00	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). **$40.00** per property +				$ 0.00	
TOTAL FEES ENCLOSED =				$ 990.00	
				Amount to be: refunded	$
				charged	$

a. ☒ A check in the amount of $ **990.00** to cover the above fees is enclosed

b. ☐ Please charge my Deposit Account No. ____ in the amount of $ _______ to cover the above fees. A duplicate copy of this sheet is enclosed.

c. ☒ The Assistant Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No 23-0650. A duplicate copy of this sheet is enclosed.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

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REGISTRATION NUMBER

PATENT APPLICATION/PCT
Attorney Docket No. 702-002116

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re application of	:	
Dirk E. M. VAN DYCK	:	**METHOD AND DEVICE FOR**
and Piotr Tomasz JEDRASIK	:	**CORRECTING PROXIMITY EFFECTS**
International Application	:	
No. PCT/BE99/00076	:	
International Filing Date	:	
14 June 1999	:	
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16 June 1998	:	
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Pittsburgh, Pennsylvania
December 15, 2000

PRELIMINARY AMENDMENT

BOX PCT
Assistant Commissioner for Patents
Washington, DC 20231

Sir:

Prior to initial examination, please amend the above-identified patent application as follows:

IN THE SPECIFICATION:

Page 1, after the title, insert the following heading:

--BACKGROUND OF THE INVENTION--.

Page 1, after line 32, insert the following heading:

--<u>SUMMARY OF THE INVENTION</u>--.

Page 2, line 2, after "comprising" insert --the steps--.

Page 2, after line 38, insert the following:

--$d^{(\ell)} = d^{(\ell-1)} + (K^{v}K+\lambda B(D))^{-1}\, K^{v} r^{(\ell-1)}$ $\qquad r^{(\ell)} = a\text{-}Kd^{(\ell)}$--

Page 3, line 6, delete "K*" and substitute therefor --K^{v}--.

Page 5, after line 27, insert the following heading:

--<u>BRIEF DESCRIPTION OF THE DRAWINGS</u>--.

Page 6, after line 12, insert the following heading:

--<u>DESCRIPTION OF THE PREFERRED EMBODIMENT</u>--.

Page 8, after line 14, delete

"$d^{(\ell)} = d^{(\ell-1)} + (K^{*}K+\lambda B(D))^{-1}\, K^{*} r^{(\ell-1)}$ $\qquad r^{(\ell)} = a\text{-}Kd^{(\ell)}$"

and substitute therefor

--$d^{(\ell)} = d^{(\ell-1)} + (K^{v}K+\lambda B(D))^{-1}\, K^{v} r^{(\ell-1)}$ $\qquad r^{(\ell)} = a\text{-}Kd^{(\ell)}$--

Page 8, line 19, delete "K*" and substitute therefor --K^{v}--.

Page 11, after line 18, insert the following heading:

--Table 1--.

Page 11, line 33, delete "en" and substitute therefor --and--.

<u>IN THE CLAIMS</u>:

Original claims 1-20 were amended during Chapter II proceedings by substituting new claims 1-18 in a letter dated October 30, 2000. Please cancel original claims 1-20 and cancel amended claims 1-18 and rewrite them as new claims 21-37 as follows:

--21. A method for determining a precompensated pattern of exposure doses of an electron beam required per pattern position to obtain a desired pattern in a coating on a substrate, the method comprising the steps of:

determining a smearing function of the electron beam; and

determining a precompensated pattern with the smearing function and a desired pattern, wherein the determination is performed such that electron beam exposure doses contain almost exclusively positive values and that the electron beam exposure doses are smooth relative to each other, wherein the step of determining the precompensated pattern comprises the steps of:

a) estimating a regularization parameter;

b) determining a precompensated pattern with all pattern points of the desired pattern with the exception of a determined pattern point;

c) smearing the precompensated pattern again with the smearing function in order to predict the dose of the determined pattern point;

d) repeating steps b) and c) for each pattern point;

e) repeating steps a) to d) with an adapted regularization parameter until a final value of a regularization parameter is obtained; and

f) determining the precompensated pattern with the final value of the regularization parameter.

22. The method as claimed in claim 21, wherein step b) is determined utilizing the following iterative equation:

$$d^{(\ell)} = d^{(\ell-1)} + (K^{v}K+\lambda B(D))^{-1}\, K^{v} r^{(\ell-1)} \qquad r^{(\ell)} = a-Kd^{(\ell)}$$

with $d^{(0)} = 0$ and $r^{(0)} = a$

wherein a is a vector with the doses of the desired pattern as elements, d is a vector with the exposure doses of the precompensated pattern, K is the smearing function in matrix form, K^{v} is the Hermitian conjugate of the smearing function K, B is an operator and λ a regularization parameter.

23. The method as claimed in claim 22, wherein the operator B is defined as follows:

$$B(D) = \sum_{i} \left(\frac{d_i}{d_{tot}}\right) \ell n \left(\frac{d_i}{d_{tot}}\right)$$

in which the summation takes place over all pattern points, d_i is the i^{th} element of the vector d, and d_{tot} represents the summation over all elements of the vector d.

24. The method as claimed in claim 21, wherein the final value of the regularization parameter in step e) is the regularization parameter

$$\frac{1}{N}\sum_{k=1}^{N}\left(a_k - \left[Kd_k(\lambda)\right]_k\right)^2$$

wherein N is the total number of pattern points, a is a vector with the doses of the desired pattern as elements, d is a vector with the exposure doses of the precompensated pattern and K is the smearing function in matrix form.

25. The method as claimed in claim 21, wherein the final value of the regularization parameter in step e) is the minimal regularization parameter

$$\frac{1}{N}\sum_{k=1}^{N}\left(a_k - \left[Kd^k(\lambda)\right]_k\right)^2 W_{kk}(\lambda)$$

wherein N is the total number of pattern points, a is a vector with the doses of the desired pattern as elements, d is a vector with the exposure doses of the precompensated pattern, K is the smearing function in matrix form and w_{kk} is defined as:

$$w_{kk}(\lambda) = \left[\frac{1 - a_{kk}(\lambda)}{1 - \frac{1}{N}\sum_{j=1}^{N} a_{jj}(\lambda)} \right]^2$$

with a_{kk} the elements of the matrix $A = K(K^TK+\lambda L(D)^TL(D))^{-1}K^T$ and L the Laplace operator.

26. The method as claimed in claim 21, wherein after step e) the step is performed of training a neural network using one or more desired first patterns and the associated precompensated patterns.

27. The method as claimed in claim 26, wherein the precompensated pattern associated with a second desired pattern can be determined with the trained neural network.

28. The method as claimed in claim 27, wherein the first desired pattern is a relatively simple training pattern and the second desired pattern is a partial pattern of an integrated circuit.

29. The method as claimed in claim 28, wherein two or more partial patterns can be combined into a composite pattern of the integrated circuit.

30. The method as claimed in claim 26, wherein the neural network is a radial base function network.

31. The method as claimed in claim 26, wherein the neural network is implemented in hardware.

32. The method as claimed in claim 31, wherein the neural network is implemented in analog hardware.

33. The method as claimed in claim 21, wherein the smearing function is made up of at least two Gaussian functions.

34. The method as claimed in claim 33, wherein an exponential function is added to the smearing function.

35. The method as claimed in claim 33, wherein the parameters of the Gaussian functions can be determined using statistical simulations.

36. The method as claimed in claim 33, wherein the parameters of the Gaussian functions can be determined by measurements.

37. A device for determining the exposure dose of an electron beam required per pattern position to obtain a desired pattern in a coating on a substrate, comprising electronic circuit means for implementing a neural network having weighting factors determined by training the neural network by using as inputs one or more desired patterns and corresponding precompensation patterns determined by the steps of:

a) estimating a regularization parameter;

b) determining a precompensated pattern with all pattern points of the desired pattern with the exception of a determined pattern point;

c) smearing the precompensated pattern again with the smearing function in order to predict the dose of the determined pattern point;

d) repeating steps b) and c) for each pattern point;

e) repeating steps a) to d) with adapted regularization parameter until a final value of a regularization parameter is obtained; and

f) determining the precompensated pattern with the final value of the regularization parameter.--

<u>IN THE ABSTRACT</u>:

After the claims, please insert a page containing the <u>Abstract Of The Disclosure</u>, which is attached hereto as a separately typed page.

REMARKS

The specification has been amended to place it into conformance with standard United States Patent practice.

On October 30, 2000, Applicants submitted substitute sheets containing amended claims 1-18 for the above-identified PCT application. Original claims 1-20 have been canceled by this Preliminary Amendment and amended claims 1-18 have been cancelled and rewritten as new claims 21-37 to eliminate the multiple dependencies and to bring the claims into conformance with standard United States Patent practice.

An Abstract Of The Disclosure has been added as a separately typed page to be inserted after the claims.

Entry of this Preliminary Amendment is respectfully requested.

Respectfully submitted,

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METHOD AND DEVICE FOR CORRECTING PROXIMITY EFFECTS

The present invention relates to a method and device for determining the exposure dose of an electron beam required per pattern position to obtain a desired pattern in a coating.

In the manufacture of the latest generations of integrated circuits use is preferably made of focused electron beams in lithographic processes instead of making use of the usual optical lithographic techniques, since these latter techniques are subject to limitations in terms of resolution as a result of diffraction of the used laser light. The resolution of the integrated circuit obtained with such electron beam lithography is greater, although it is limited by scattering of the electrons in the coating. Methods are known for minimizing scattering effects or compensating therefor in advance and thereby improving the resolution of the obtained integrated circuits.

The known methods have the drawback however that scattering effects can themselves only be minimized to a limited degree, while advance compensation according to the known method requires many calculations and therefore needs a long calculation time. For the manufacture of integrated circuits for instance a very large number of pattern points, often in the order of magnitude of 10^{10} pattern points, must be "written", while the number of calculations required for this purpose amounts to a multiple thereof. As a result a practically real time precompensation for the smearing or blurring effects cannot be implemented.

The object of the present invention is to obviate this drawback and also provide additional advantages.

The present invention therefore relates to a method for determining the precompensated pattern of exposure doses of an electron beam required per pattern

position to obtain a desired pattern in a coating on a substrate, comprising of:

- determining the smearing function (blur function) of the electron beam;

- determining the precompensated pattern with the smearing function and the desired pattern, wherein the determination is performed such that the exposure doses contain almost exclusively positive values and that the exposure doses are at least to some extent smooth relative to each other.

Since a negative value for the exposure doses of an electron beam has no physical significance and cannot therefore be realized, the determination of the exposure doses of the precompensated pattern is performed such that it assumes (almost) exclusively positive values. A smooth solution is furthermore obtained since strong oscillations in the smearing function have no physical basis but are caused solely by mathematical instability of the calculations.

In a preferred embodiment of the invention the method comprises the steps of:

a) estimating a regularization parameter;

b) determining a precompensated pattern with all pattern points of the desired pattern with the exception of a determined pattern point;

c) smearing the precompensated pattern again with the smearing function in order to predict the dose of the determined pattern point;

d) repeating steps b and c for each pattern point;

e) repeating steps a to d with adapted regularization parameter until a final value of a regularization parameter is obtained;

f) determining the precompensated pattern with the final value of the regularization parameter.

According to a further embodiment of the invention step b) comprises the following iterative definition:

with $d^{(0)} = 0$ and $r^{(0)} = a$ in which a is a vector with the doses of the desired pattern as elements, d is a vector with the exposure doses of the precompensated pattern, K is the smearing function in matrix form, K^* is the Hermitian conjugate of the smearing function K, B is an operator and λ a regularization parameter.

According to a further embodiment of the invention operator B is defined as follows:

$$B(D) = \sum_i \left(\frac{d_i}{d_{tot}}\right) \ln\left(\frac{d_i}{d_{tot}}\right)$$

in which the summation takes place over all pattern points, d_i is the i^{th} element of the vector d, and d_{tot} represents the summation over all elements of the vector d.

According to a further embodiment of the invention the final value of the regularization parameter in the above mentioned step e) is the regularization parameter wherein

$$\frac{1}{N}\sum_{k=1}^{N} (a_k - [Kd_k(\lambda)]_k)^2$$

in which N is the total number of pattern points, a is a vector with the doses of the desired pattern as elements, d is a vector with the exposure doses of the precompensated pattern and K the smearing function in matrix form.

According to a further embodiment of the invention the final value of the regularization parameter in step e) is the minimal regularization parameter wherein

$$\frac{1}{N}\sum_{k=1}^{N}(a_k - [Kd^k(\lambda)]_k)^2 w_{kk}(\lambda)$$

in which N is the total number of pattern points, a is a vector with the doses of the desired pattern as elements, d is a vector with the exposure doses of the precompensated pattern, K is the smearing function in matrix form and w_{kk} is defined as:

$$w_{kk}(\lambda) = [\frac{1-a_{kk}(\lambda)}{1-\frac{1}{N}\sum_{j=1}^{N}a_{jj}(\lambda)}]^2$$

with a_{kk} the elements of the matrix $A = K(K^TK+\lambda L(D)^T L(D))^{-1}K^T$ and L the discrete Laplace transformation.

According to a further embodiment of the invention after step e) the step is performed of training a neural network using one or more desired first patterns and the associated precompensated patterns.

According to a further embodiment of the invention the precompensated pattern associated with a second desired pattern can be determined with the trained neural network, wherein in a further embodiment the first desired pattern is a relatively simple training pattern and the second desired pattern is the partial pattern of an integrated circuit, and wherein in a further embodiment two or more partial patterns can be combined into a composite pattern of the integrated circuit.

By determining the associated precompensated pattern of exposure doses for a known desired pattern, which is preferably simple, and then establishing the relation between the weighting factors of a neural network, is ensured that for a second desired pattern, which may be complicated, obtaining the relation between this pattern and the associated exposure doses is determined in very efficient and rapid manner by the neural network. The first pattern is generally a relatively simple training pattern, while the second

pattern is for instance the pattern of a very complicated integrated circuit.

In a preferred embodiment of the invention the above stated neural network is implemented in hardware, whereby determining of the relation between a pattern and the exposure dose associated therewith is performed in more rapid manner, for instance within 60 ns for each pattern point and within 10 minutes for a pattern of 10^{10}.

According to a preferred embodiment of the invention the smearing function is made up of at least two Gaussian functions, to which an exponential function is optionally added. Parameters of the Gaussian functions and optionally the exponential function can be determined by means of statistical simulation of the system of electron beam transmitting equipment and the relevant coating and substrate of the integrated circuit for manufacture.

In another embodiment of the invention parameters are determined by performing measurements on the system of electron beam transmitting equipment and the relevant coating with substrate.

The present invention also relates to a device for determining the exposure dose of an electron beam required per pattern position to obtain a desired pattern in a coating on a substrate, comprising an electronic circuit for implementing said neural network with weighting factors determined in the above stated manner.

The invention will be elucidated hereinbelow with reference to a preferred embodiment thereof, wherein use will be made of the annexed drawings, in which:

- figure 1 shows a schematic overview of a preferred embodiment of a device according to the invention;

- figures 2a-2c show a schematic overview of the determination of a precompensated pattern of 3x3 pattern points;

- figure 3 shows a desired training pattern of 256x256 pattern points;

- figure 4 shows the training pattern of figure 3 after smearing;
- figure 5 shows a graph in which for the training pattern of figure 3 the prediction error is plotted as a function of the chosen regularization parameter;
- figure 6 shows the training pattern of figure 3 after precompensation;
- figure 7 shows the precompensated pattern of figure 6 after smearing; and
- figure 8 is a schematic representation of a neural network for determining precompensated patterns.

In an arrangement of equipment for transmitting an electron beam and a substrate 1 with coating 2 for processing, a beam of electrons 3 is directed at a position or pattern point of a coating 2 on a substrate 1. The interaction of the incident electron beam 3 with the coating or resist film 2 and the underlayer or substrate 1 results in a scattering of the electrons in coating 2 which causes smearing or proximity effects. When for instance a primary electron penetrates into the coating, a part of its energy is transferred to electrons of the atoms of the coating, which causes ionization or excitation thereof. A collision between electrons with a large transfer of energy generates a secondary electron which generally has a direction of movement perpendicular to that of a primary electron.

Smearing effects in electron beam lithography relate more generally to the process whereby the resolution of the exposed pattern is reduced by primary electron scattering (forward scattering) and secondary electron excitation (backward scattering) in the coating and the substrate of an integrated circuit for manufacture. Sharp features such as angles in the desired pattern are rounded, line thicknesses and interspaces are modified and in particular extreme cases some features even disappear completely or are merged in incorrect manner with adjacent features.

The smearing effects or proximity effects can be described by a smearing function, which shows the relation between on the one hand the exposure doses of a determined pattern point of a pattern for manufacturing in the coating and on the other the doses actually absorbed by this pattern point and adjacent pattern points. The effect of the smearing is thus established in the smearing function.

Assuming that exposure and smearing are linearly and spatially invariant and that for a numeric solution a discrete representation is preferred, the above can be expressed in matrix form as follows: $A = KD$, in which A is a column vector of which each element a_i is the total energy dose which is actually absorbed in the associated pattern point, K is a smearing matrix of which each mn^{th} element is the portion of the energy dose which is absorbed in pattern point m from a unit-exposure dose supplied to pattern point n, and D is a column vector made up of elements d_i which represent the exposure doses generated per pattern point by the electron beam equipment. Since the smearing effect is unavoidable, it is best to adapt the exposure doses d_i of the different pattern points such that the dose a_i actually absorbed in a pattern point is such that the desired pattern is still obtained.

This so-called precompensation of the exposure dose of the electron beam can be performed according to the prior art by determining the inverse of the smearing matrix K. There are many ways of generally inverting a matrix. However, these methods often take no account of physical limitations, such as in this case for instance those of the electron beam transmitters. No negative exposure doses for instance are thus possible. A further drawback of such inversion methods is that the inverted matrix has many oscillations. In addition, for inversion of the smearing matrix for a partial pattern of for instance 256x256 pattern points the inversion of a smearing matrix with dimensions of 65536x65536 has to be

calculated, which requires an enormous amount of calculating time.

Figures 2a to 2c show a desired pattern (A). The pattern is built up of 9 pattern points a_i wherein i varies from 1 to 9. This desired pattern must be precompensated in order to be able to provide the desired pattern after exposure to the smearing electron beam, i.e. the values of d_i, with i varying from 1 to 9, have to be determined.

The precompensated pattern is first of all determined making use of the doses a_i with i from 2 to 9, wherein pattern point 1 is not therefore taken into account (figure 2a). This precompensated pattern is determined on the basis of the following expression:

$$d^{(l)} = d^{(l-1)} + (K^{*}K + \lambda B(D))^{-1} K^{*} r^{(l-1)} \qquad r^{(l)} = a - Kd^{(l)}$$

with $d^{(0)} = 0$ and $r^{(0)} = a$

wherein a is a vector with the doses of the desired pattern as elements, d is a vector with the exposure doses of the precompensated pattern , K is the smearing function in matrix form, K^{*} is the Hermitian conjugate of smearing function K, B is an operator and λ a regularization parameter. The value of the regularization parameter can be chosen at random, in this case for instance $\lambda = 0$.

The operator B imposes a limitation and can be defined as follows:

$$B(D) = \sum_i \left(\frac{d_i}{d_{tot}}\right) \ln\left(\frac{d_i}{d_{tot}}\right)$$

in which the summation takes place over all pattern points, d_i is the i^{th} element of the vector d, and d_{tot} represents the summation over all elements of the vector d.

The thus determined precompensated pattern is then smeared once again on the basis of the known

smearing function, whereby the predicted dose Kd of pattern point 1 is determined.

The above procedure is then repeated successively (figures 2b and 2c) for the second to ninth pattern point (i=2,..,9), wherein all pattern points with the exception of one pattern point are used each time.

On the basis of the above results, the least squares prediction error over all pattern points is determined, which will be further explained later.

The above procedure is subsequently repeated with different values for the regularization parameter λ, for instance λ_2= 0.001, λ= 0.002 etc. The regularization parameter is eventually chosen wherein the least squares prediction error over all pattern points is minimal. This regularization parameter is then chosen as the optimal regularization parameter λ_{opt}. The final precompensated pattern is then determined on the basis of this optimal regularization parameter λ_{opt}.

For this purpose the minimum is determined of the expression:

$$\frac{1}{N}\sum_{k=1}^{N} (a_k - [Kd^k(\lambda)]_k)^2 w_{kk}(\lambda)$$

in which N is the total number of pattern points, a is a vector with the doses of the desired pattern as elements, d is a vector with the exposure doses of the precompensated pattern, K is the smearing function in matrix form and w_{kk} is defined as:

$$w_{kk}(\lambda) = [\frac{1-a_{kk}(\lambda)}{1-\frac{1}{N}\sum_{j=1}^{N} a_{jj}(\lambda)}]^2$$

with a_{kk} the elements of the matrix $A = K(K^T K+\lambda L(D)^T L(D))^{-1} K^T$ and L the Laplace operator.

The smearing function resulting from forward scattering and backward scattering of the electrons of

the electron beam can be determined in different ways. It can be determined on the basis of measurements of the impulse response of the equipment for transmitting the electron beam on a test object. The smearing function can also be determined using diverse Monte Carlo techniques. In the first method of determination all physical aspects of the equipment used are taken into account. In the latter mentioned method of determination only a model of the reality is used, although the determination is however easier to perform without requiring extensive measurements.

Gaussian functions are preferably used as approximation for the smearing functions determined in any of the above described methods. The smearing function is in this case "fitted" for instance with a scattering fit model of a double Gaussian function (for both forward and backward scattering properties of the electrons), a triple Gaussian function or a double Gaussian function with a decreasing exponential function. The choice of the scattering fit model depends on the dimensions of the components to be distinguished in the test object (resolution). At dimensions smaller than 100 nm the choice hereof becomes critical: at such small dimensions the triple Gaussian functions or double Gaussian functions with decreasing exponential function are recommended. A smearing function with double Gaussian function can be described with 3 parameters, while the other two stated scattering fit models can be described with 4 parameters, which implies a great reduction in the quantity of data for processing.

Figure 3 shows a desired pattern of 256x256 pattern points. Smearing with a smearing function in the form of a double Gaussian function with α= 50 nm, ß= 3.45 and ^{n}= 1.36 produces the smeared pattern of figure 4. It is clearly visible that much detail in the pattern has been lost, which means a limitation in the resolution to be obtained of the pattern for manufacture. Application of the method according to the invention produces an

optimal regularization parameter of $\lambda_{opt} = 0.07042$, which is shown in figure 5, in which the error in the pattern is minimal at this value of λ. The precompensated pattern calculated with this value of λ and the associated smeared pattern are shown respectively in figures 6 and 7. Comparison of the results of figure 7 with those of figure 3 shows that the precompensation of the pattern with a desired pattern produces a smeared pattern with a greatly improved resolution. Components for distinguishing with dimensions of less than 100 nm, for instance in an integrated circuit, can hereby be realized. A comparison of the results of the method described herein with those of other correction methods is shown in table 1. The degree of error of the correction methods is defined here as the summation of the difference between the calculated exposure doses and the ideal precompensated exposure doses divided by the number of pattern points.

Correction method	degree of error in %
Uncorrected	10.2 %
Truncating	10.2 %
Shifting and scaling	12.2 %
Present method	4.9 %

From the above can be seen that the present method of determining a precompensated pattern produces by far the smallest degree of error compared to the other usual methods.

The precompensated pattern and the desired pattern are subsequently used as training set or training patterns for a neural network. A part of such a network is shown schematically in figure 8 en is represented by the expression

$$a_i = \sum_{j=1}^{9} w_{ij} h_{ij}(x)$$

i.e. the dose a_i is expressed in a set of 9 basic functions h_{ij}, in this case radial functions.

After training of the neural network a precompensated pattern can be determined for another random desired pattern in very rapid manner. A random pattern can for instance be a pattern of 512 by 512 pattern points forming a partial pattern of an integrated circuit. Various partial patterns can then be combined (clustered) to form one pattern which comprises the whole integrated circuit or at least a part thereof.

The above described neural network can be implemented in hardware, and preferably in analog hardware since the calculating speed of neural networks implemented in this manner is very great. The calculating time for precompensation of a pattern thus amounts to less than 60 ns per pattern point. Precompensation of a pattern of an integrated circuit of about 10^{10} pattern points requires in this case only about 10 minutes on present personal computers.

The invention is further described in the non-prepublished doctoral thesis with the title "Proximity effects correction in electron beam nanolithography", the entire content of which should be deemed as interpolated herein.

NEW CLAIMS

1. Method for determining the precompensated pattern of exposure doses of an electron beam required per pattern position to obtain a desired pattern in a coating on a substrate, comprising of:

- determining the smearing function of the electron beam;

- determining the precompensated pattern with the smearing function and the desired pattern, wherein the determination is performed such that the exposure doses contain almost exclusively positive values and that the exposure doses are smooth relative to each other, wherein the step of determining the precompensated pattern comprises the steps of:

a) estimating a regularization parameter;

b) determining a precompensated pattern with all pattern points of the desired pattern with the exception of a determined pattern point;

c) smearing the precompensated pattern again with the smearing function in order to predict the dose of the determined pattern point;

d) repeating steps b and c for each pattern point;

e) repeating steps a to d with adapted regularization parameter until a final value of a regularization parameter is obtained;

f) determining the precompensated pattern with the final value of the regularization parameter.

2. Method as claimed in claim 1, wherein step b) comprises the following iterative definition:

$$d^{(l)} = d^{(l-1)} + (K^*K+\lambda B(D))^{-1}K^*r^{(l-1)} \qquad r^{(l)} = a-Kd^{(l)}$$

with $d^{(0)} = 0$ and $r^{(0)} = a$

wherein a is a vector with the doses of the desired pattern as elements, d is a vector with the exposure doses of the precompensated pattern, K is the smearing function in matrix form, K^* is the Hermitian conjugate of the smearing function K, B is an operator and λ a regularization parameter.

3. Method as claimed in claim 2, wherein the operator B is defined as follows:

$$B(D) = \sum_i \left(\frac{d_i}{d_{tot}}\right) \ln\left(\frac{d_i}{d_{tot}}\right)$$

in which the summation takes place over all pattern points, d_i is the i^{th} element of the vector d, and d_{tot} represents the summation over all elements of the vector d.

4. Method as claimed in claim 1, wherein the final value of the regularization parameter in step e) is the regularization parameter wherein

$$\frac{1}{N}\sum_{k=1}^{N} (a_k - [Kd_k(\lambda)]_k)^2$$

wherein N is the total number of pattern points, a is a vector with the doses of the desired pattern as elements, d is a vector with the exposure doses of the precompensated pattern and K the smearing function in matrix form.

5. Method as claimed in claim 1, wherein the &6nal value of the regularization parameter in step e) is the minimal regularization parameter wherein N

$$\frac{1}{N}\sum_{k=1}^{N} (a_k - [Kd^k(\lambda)]_k)^2 w_{kk}(\lambda)$$

is the total number of pattern points, a is a vector with the doses of the desired pattern as elements, d is a

vector with the exposure doses of the precompensated pattern, K is the smearing function in matrix form and w_{kk} is defined as:

$$w_{kk}(\lambda) = \left[\frac{1-a_{kk}(\lambda)}{1-\frac{1}{N}\sum_{j=1}^{N} a_{jj}(\lambda)}\right]^2$$

with a_{kk} the elements of the matrix $A = K(K^TK+\lambda L(D)^TL(D))^{-1}K^T$ and L the Laplace operator.

6. Method as claimed in any of the foregoing claims, wherein after step e) the step is performed of training a neural network using one or more desired first patterns and the associated precompensated patterns.

7. Method as claimed in claim 6, wherein the precompensated pattern associated with a second desired pattern can be determined with the trained neural network.

8. Method as claimed in claims 6 and 7, wherein the first desired pattern is a relatively simple training pattern and the second desired pattern is the partial pattern of an integrated circuit.

9. Method as claimed in claim 8, wherein two or more partial patterns can be combined into a composite pattern of the integrated circuit.

10. Method as claimed in any of the claims 6-9, wherein the neural network is a radial base function network.

11. Method as claimed in any of the claims 6-10, wherein the neural network is implemented in hardware.

12. Method as claimed in claim 11, wherein the neural network is implemented in analog hardware.

13. Method as claimed in any of the foregoing claims, wherein the smearing function is made up of at least two Gaussian functions.

14. Method as claimed in claim 13, wherein an exponential function is added to the smearing function.

15. Method as claimed in claim 13 or 14, wherein the parameters of the Gaussian functions can be determined using statistical simulations.

16. Method as claimed in claim 13 or 14, wherein the parameters of the Gaussian functions can be determined by measurements.

17. Device for determining the exposure dose of an electron beam required per pattern position to obtain a desired pattern in a coating on a substrate, comprising electronic circuit means for implementing a neural network with weighting factors determined as claimed in any of the foregoing claims.

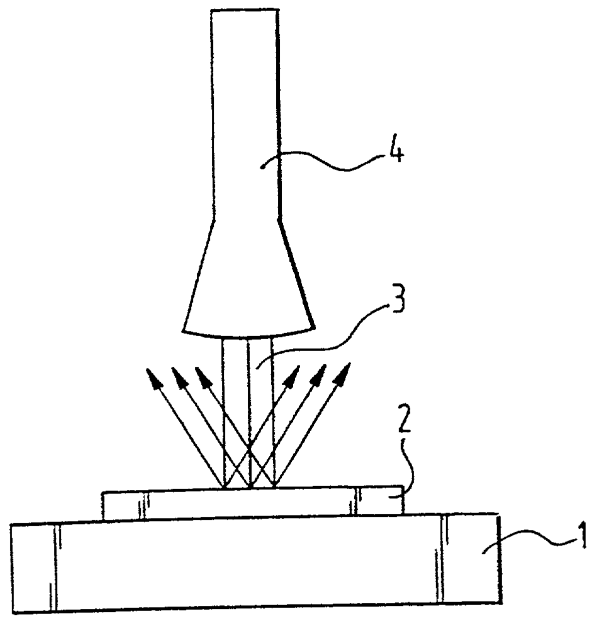
18. Integrated circuits manufactured with the device of claim 17 or according to the method of any of the claims 1-16.

METHOD AND DEVICE FOR CORRECTING PROXIMITY EFFECTS

ABSTRACT OF THE DISCLOSURE

The present invention relates to a method for determining the precompensated pattern of exposure doses of an electron beam required per pattern position to obtain a desired pattern in a coating on a substrate, comprising the steps of: determining a smearing function of the electron beam; determining a precompensated pattern with the smearing function and the desired pattern, wherein the determination is performed such that exposure doses contain almost exclusively positive values and the exposure doses are smooth relative to each other.

FIG. 1



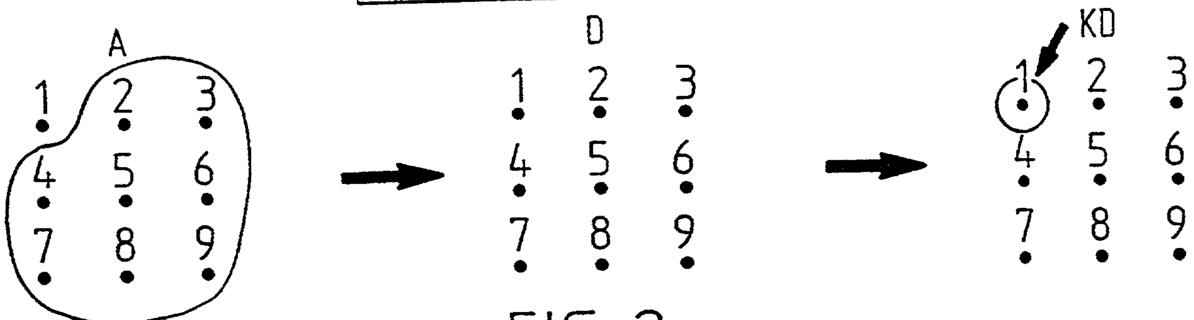


FIG. 2a

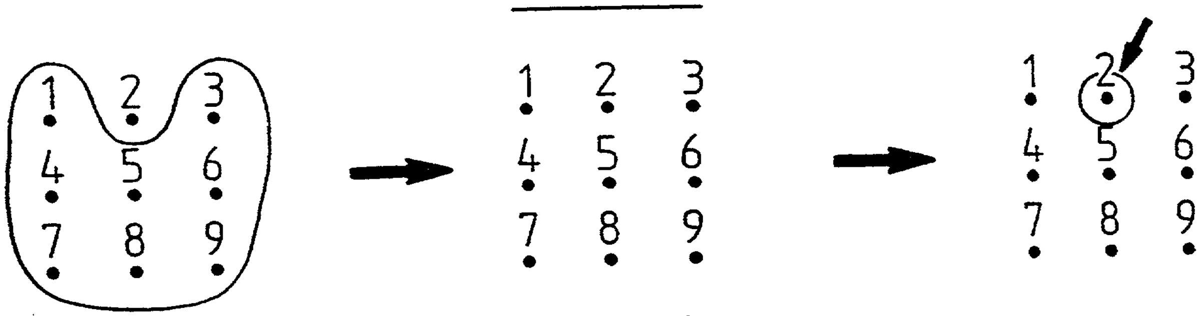


FIG. 2b

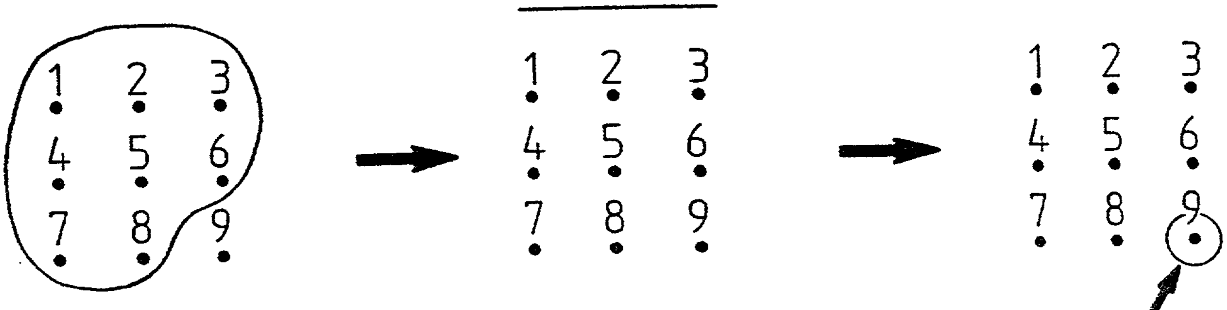


FIG. 2c

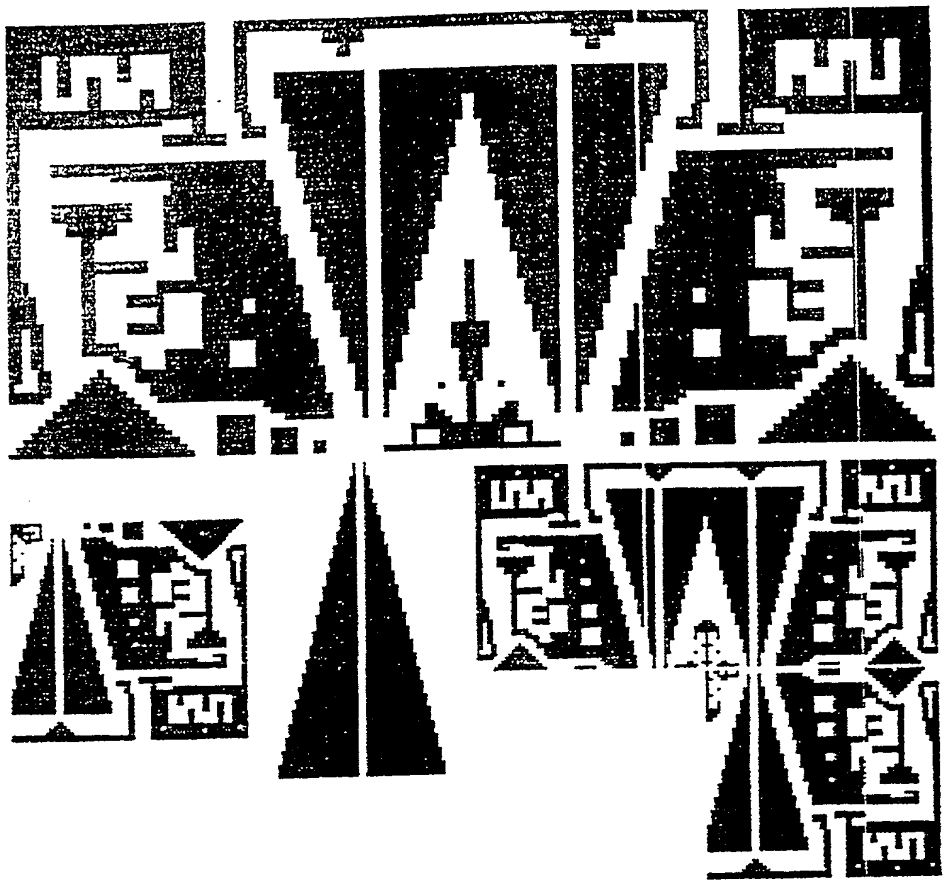


FIG. 3

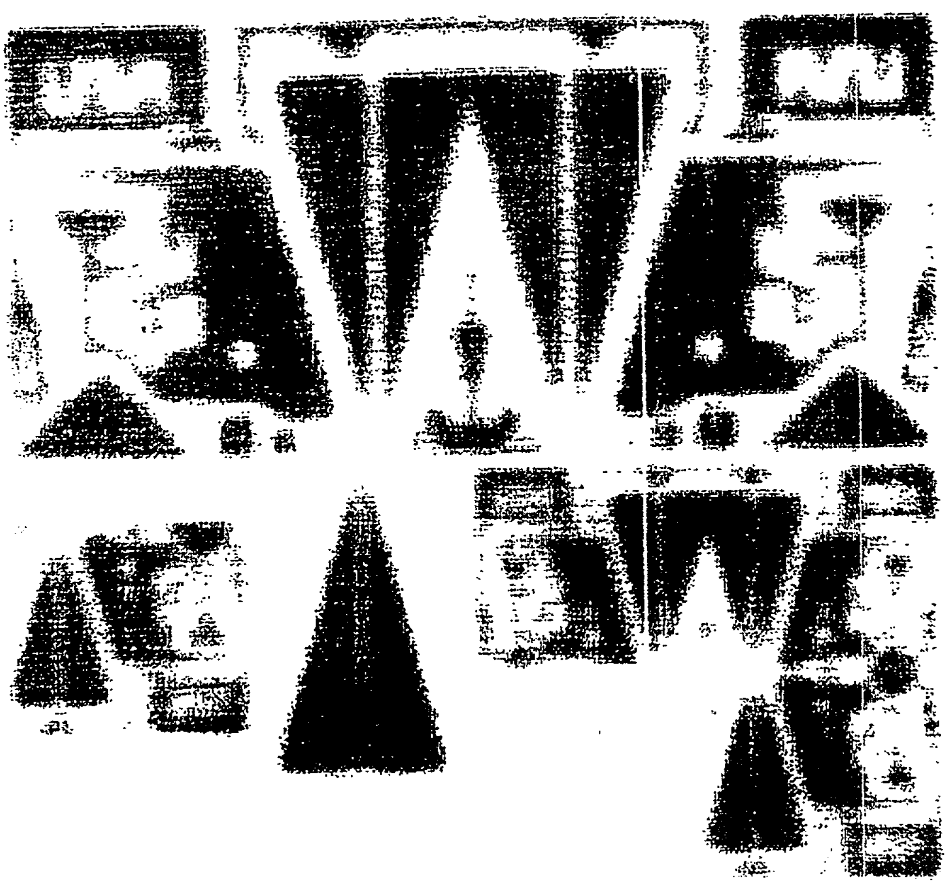
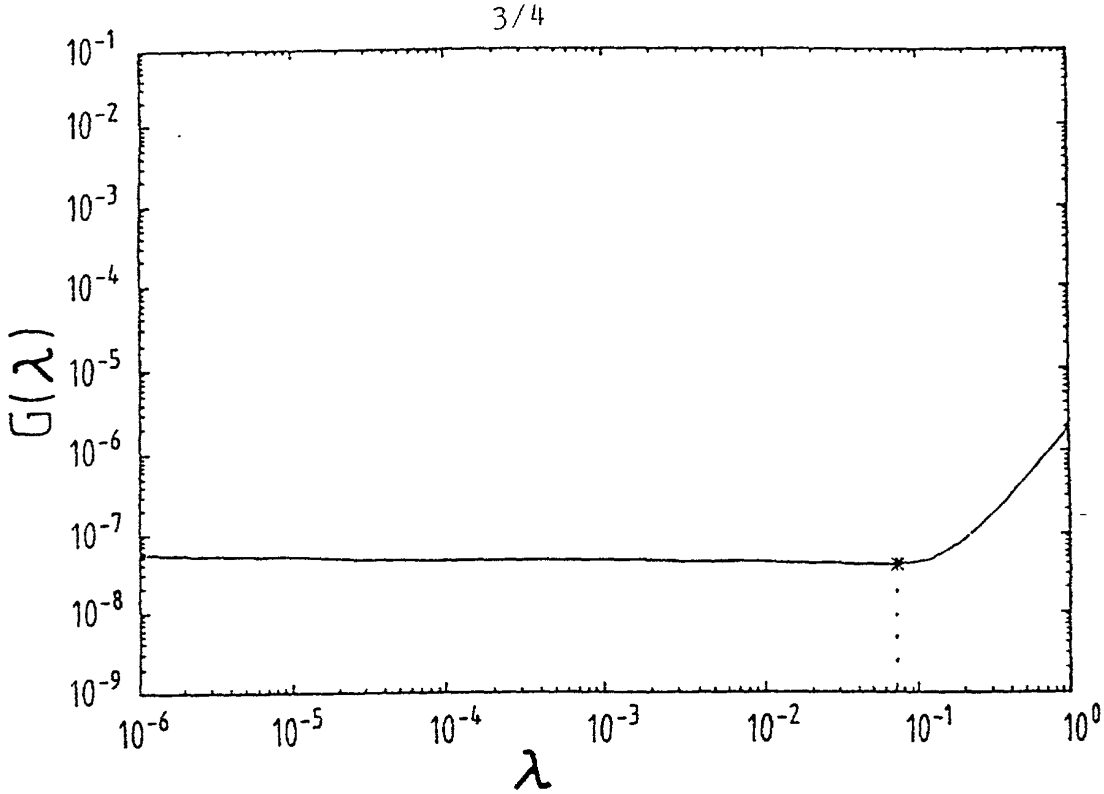


FIG. 4


G(λ)
λ
10-1
10-2
10-3
10-4
10-5
10-6
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10-2
10-1
100

FIG. 5

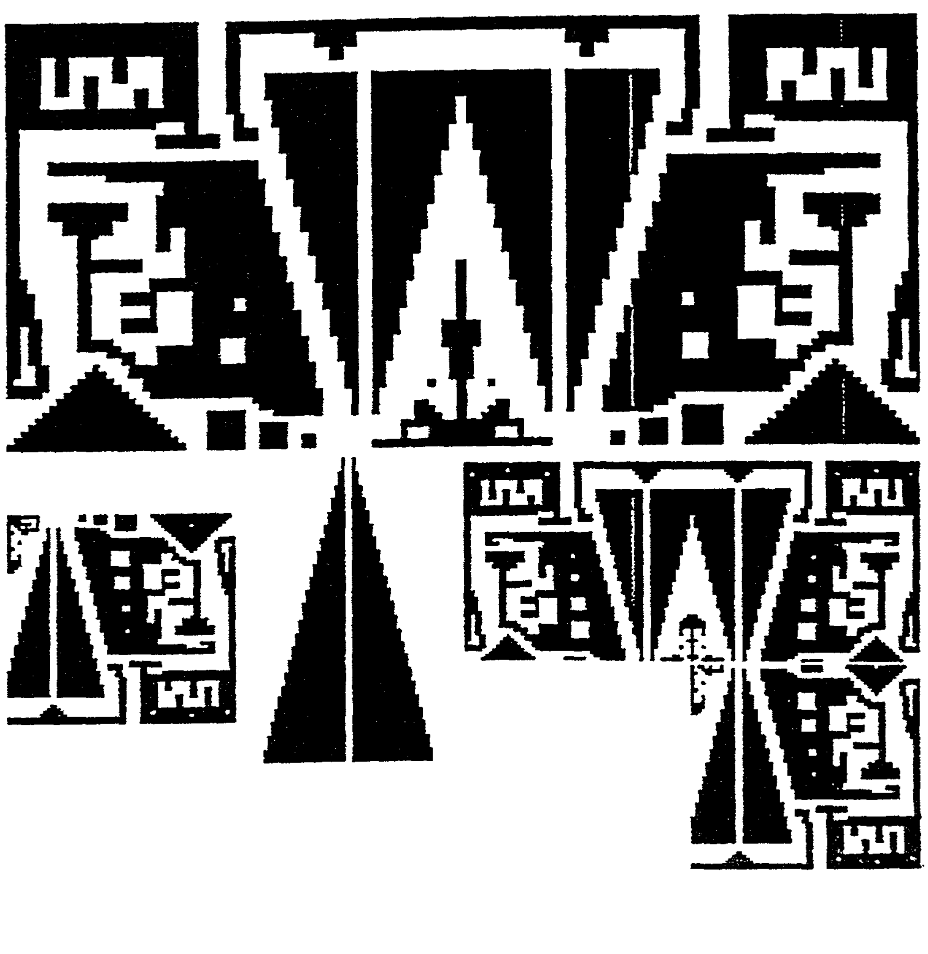

FIG. 6

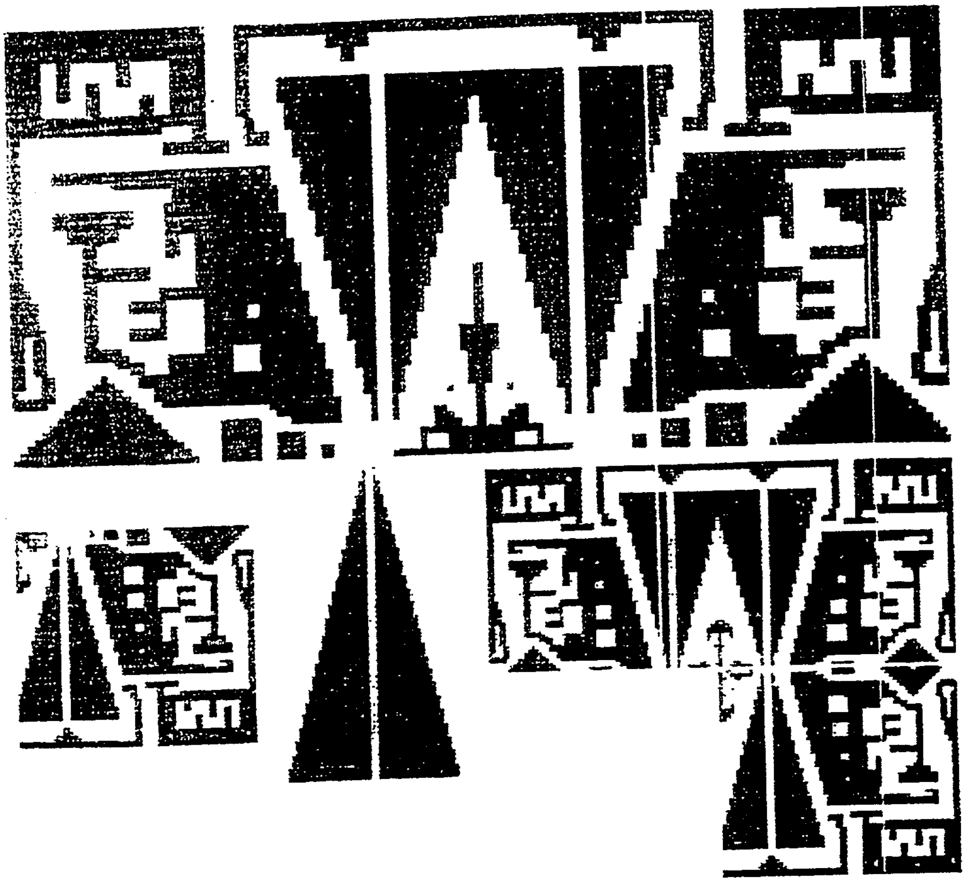

FIG. 7

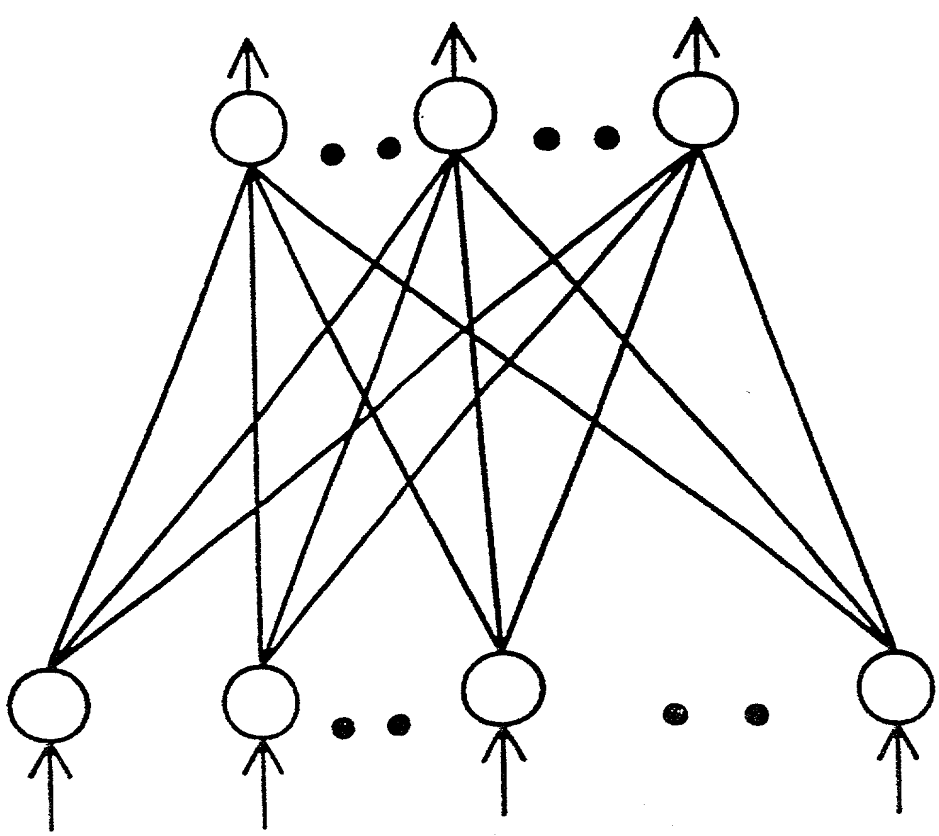

FIG. 8

Declaration and Power of Attorney For Patent Application

English Language Declaration

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name,

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled

Method and Device for Correcting Proximity Effects

the specification of which

(check one)

☐ is attached hereto.

☒ was filed on June 14, 1999 as PCT international application ~~as~~x

~~Application Serial No~~x No. PCT/BE99/00076 and Serial No. 09/719,757, received 15 December 2000

and was amended on December 15, 2000
(if applicable)

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, §1.56(a).

I hereby claim foreign priority benefits under Title 35, United States Code, §119 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

Prior Foreign Application(s)			Priority Claimed	
1009422	The Netherlands	June 16, 1998	☒ Yes	☐ No
(Number)	(Country)	(Day/Month/Year Filed)		
1010311	The Netherlands	October 13, 1998	☒ Yes	☐ No
(Number)	(Country)	(Day/Month/Year Filed)		
			☐ Yes	☐ No
(Number)	(Country)	(Day/Month/Year Filed)		

I hereby claim the benefit under Title 35, United States Code, §120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, §112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, §1.56(a) which occurred between the filing date of the prior application and the national or PCT international filing date of this application:

(Application Serial No.)	(Filing Date)	(Status) (patented, pending, abandoned)
(Application Serial No.)	(Filing Date)	(Status) (patented, pending, abandoned)

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

POWER OF ATTORNEY: As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith. *(list name and registration number)*

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Göteborg, 2nd of April 2001-04-02

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b) citizenship is :

POLISH

With regards,

Piotr Jedrasik

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